Ozone Trends in the Lake Michigan Region

Lake Michigan Air Directors Consortium
May 22, 2002

The purpose of this document is to present the results of several recent trends analyses of ambient ozone concentrations in the Lake Michigan area. Examination of the changes in ozone air quality over time provides information on progress toward attainment and the relative effectiveness of control programs. The trends in local ozone concentrations (including basic ozone metrics, such as the number of exceedance days and the design values, and statistical analyses which account for the year-to-year variation in meteorology), local ozone precursor concentrations, and incoming (background) ozone concentrations are discussed here.

The key findings from this study are as follows:

- Since 1981, trends in 1-hour peaks are generally downward. In recent years, however, these trends are flatter.

- Most improvement in 1-hour levels is seen at sites near Lake Michigan in the vicinity of the Chicago-Milwaukee area. Less improvement is seen at sites farther downwind.

- Trends at regional (background) sites are generally flat and, possibly, increasing in recent years.

- Trends in 8-hour peaks are similar to those for 1-hour peaks, with some indication of increasing trends in recent years.

These findings demonstrate that 1-hour ozone air quality levels in the Lake Michigan area have improved over the past 20 years, and support the plans to redesignate the area to attainment for the 1-hour ozone National Ambient Air Quality Standard (NAAQS).

Local Ozone Concentrations

To provide some simple information about ozone levels in the area, several basic metrics were considered: number of 1-hour exceedance days, number of monitored violations, and 1-hour design values. These metrics are used to assess attainment of the 1-hour NAAQS[1].

[1] The ozone NAAQS is attained when the number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than 1.0, averaged over a 3-year period. An alternative means of judging attainment is to take the 4^{th} highest daily 1-hour value over a 3-year period (i.e., the design value). An exceedance is defined as a peak daily 1-hour ozone concentration equal to or greater than 0.12 ppm (125 ppb) and a violation is defined as a design value equal to or greater than 0.12 ppm (125 ppb).

The figures below show: (a) the number of exceedance days and the number of exceedance site days (Figure 1(a)); and (b) the number of hot days and the number of cooling degree days[2] (Figure 1(b)).

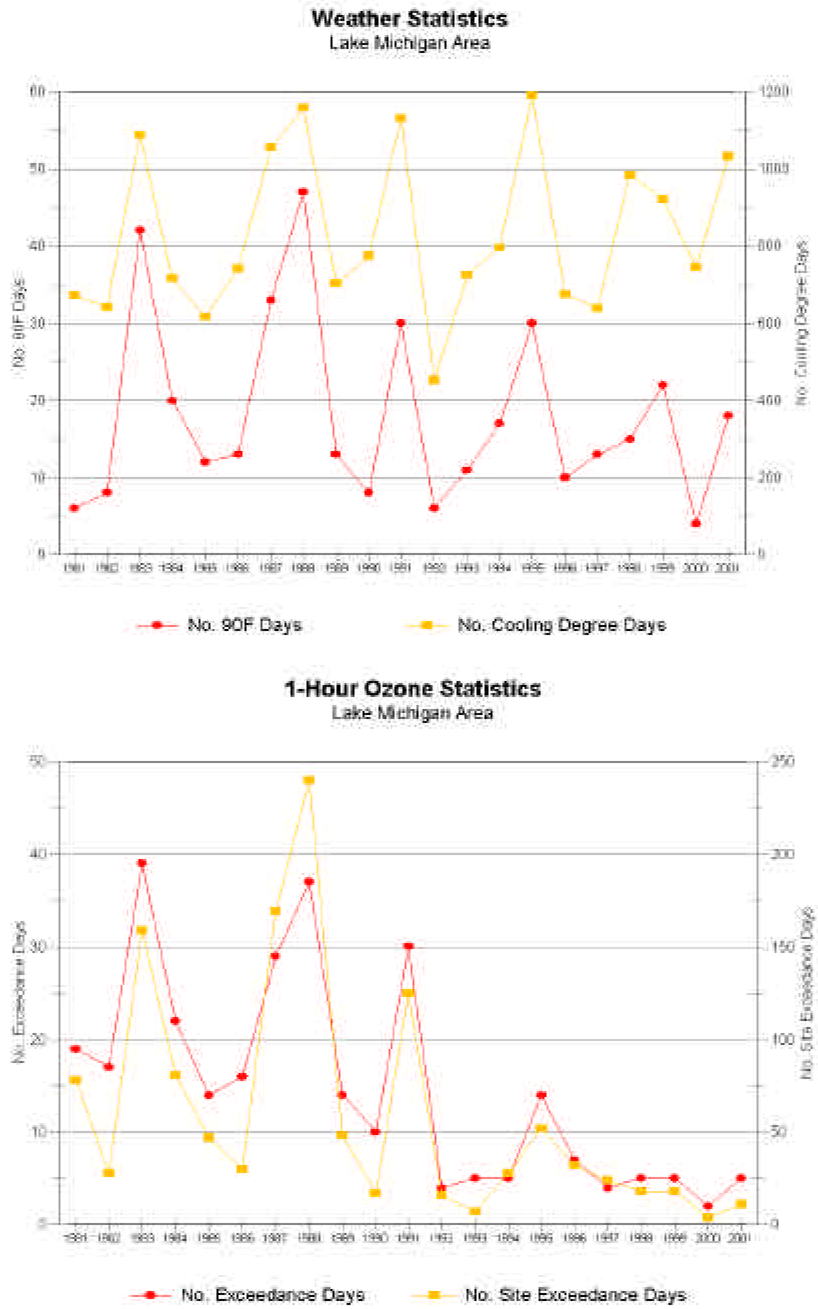

Figure 1. 1-Hour Ozone and Weather Statistics

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[2] A hot day is defined as a day with the maximum daily temperature equal to or greater than 90^{o}F, as measured at Chicago-O'Hare Airport. A cooling degree day is defined as the difference between the average daily temperature and 65^{o}F, as measured at Chicago-O'Hare Airport.

These figures show:

- The number of exceedance days in the 1980's (i.e., 207) is much more than those in the 1990's (i.e., 89); whereas the number of hot days in the 1980's (i.e., 194) is only slightly more than those in the 1990's (i.e., 162).

- During most years in the 1980's, there were more exceedance days than hot days; whereas during most years in the 1990's there were more hot days than exceedance days.

- The number of exceedance days (and site exceedance days) is generally higher during the hotter summers. In comparison to prior hot summers, there were substantially fewer exceedance days (and site exceedance days) during 1999 and 2001

Table 1 presents the number of exceedances at each monitoring site since 1981. (Note, many of these monitors operated for the past 10 years or so, any only a few operated for the entire 21-year period.) Based on this information, the number of monitors in violation of the 1-hour ozone NAAQS for each 3-year period is as follows:

3-Year Period	*Sites in Violation*
1981 – 1983	22
1982 – 1984	25
1983 – 1985	25
1984 – 1986	17
1985 – 1987	26
1986 – 1988	28
1987 – 1989	30
1988 – 1990	21
1989 – 1991	13
1990 – 1992	10
1991 – 1993	8
1992 – 1994	1
1993 – 1995	5
1994 – 1996	11
1995 – 1997	12
1996 – 1998	8
1997 – 1999	6
1998 – 2000	2
1999 - 2001	0

These results demonstrate the decrease in the number of monitors in violation of the 1-hour NAAQS.

Table 1. Number of Actual 1-Hour Exceedances

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
ILLINOIS																					
Zion																2	1				
Waukegan	4		5	4	3		7	11	2												
Libertyville	2	1	4	1	1		3	2													
Deerfield	2		3	1	2		3	2													
Northbrook																					
Cary	1	1	2																		
Elgin																					
Des Plaines			2	2												1					
Evanston	2	1	6	4	4		6	16							2			1			
Chi-Truman																					
Chi-Taft					1	1	5	1													
Univ of Chi															2						
Chi-SE Police															2						
MuseumSI																					
Chi-84th St			4	1																	
Chi-SWFP							4	7							2		1				
Chi-Jardine															2						
Chi-Edgewater							4	5													
Chi-CTA																					
ChiSearsTower																					
Alsip															1						
Calumet City															1						
Cicero			4	1			2	2													
S.Lockport		1	3																		
Lisle																					
Lemont																					
Braidwood																					

INDIANA	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Laporte																	1		1		
Michigan Cty															6	3	1		1		1
Hammond	3	1	5	4	1	2	1	5							1	1					
Ogden Dunes				3	1	3	4	10							1	1		1	1		
Gary-IITRI			5	5																	
Lowell																					
Natl Lakeshore				4		1	5	6										1	1		
Potato Creek																					
South Bend																					
Granger																				1	
Bristol																					
Valparaiso			6	3																	
Liberty School	1	2	1	1																	

MICHIGAN	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Frankfort																1					
Scottville															3	2			1	1	1
Muskegon	2	1	6	1	3	4	8	12	5	8	5	1	1	1	4	1			1	1	
Holland										1	3				4	1			1	1	1
Jenison															2	1					
Grand Rapids		1	2	1	1		3	7	3	1	2				1	2					
Parnell/Evans								4	1						1	2					
Coloma															1	2		2	1		1
Cassopolis																					
Kalamazoo																					
Traverse City																					

WISCONSIN	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Pleasant Prairie								18	4		10	2	2	1	4	2	1	2	2		1
Kenosha	7		6	4	3	1	8	17	3		1	1		1			1				
Lake Geneva								3	1												
S.Milw					2		7	9	2	1	5				2		2		1		1
Milw-Alverno							4	1	1	1	2				1						
UWM-N	8	2	10	4	4	5	8	14	6		6					1	1		1		1
Milw-App.Ave	2		3	1	2		4	2							1						
Bayside				3	1	2	9	14	5	2	10			3	2	1	1	2	1		1
Waukesha	2	4	3	1	1	2	6	1	2		1										
Grafton	4	1	9	2	2	2	6	11	4	1	1	2					2	1	1		1
Slinger							4								1						
Harrington Beach														1	2	1	3	1	1		1
Sheboygan		2	11	6			11	15	1						1		2	2	2		1
Manitowoc				6	2		11	13	1	2	5			2	1	2	2	1	1		
Kewaunee							5	9			2			1	1		1				
Newport Beach										3	4			2	1	1	2				1
Milton																					
Beloit																					
Collins															1		1				
Green Bay																					
Jefferson																					
Mayville																					
Columbus																					
Appleton															1						
Oshkosh																					
Fond du Lac																					
Milw-SE Hdqs																					

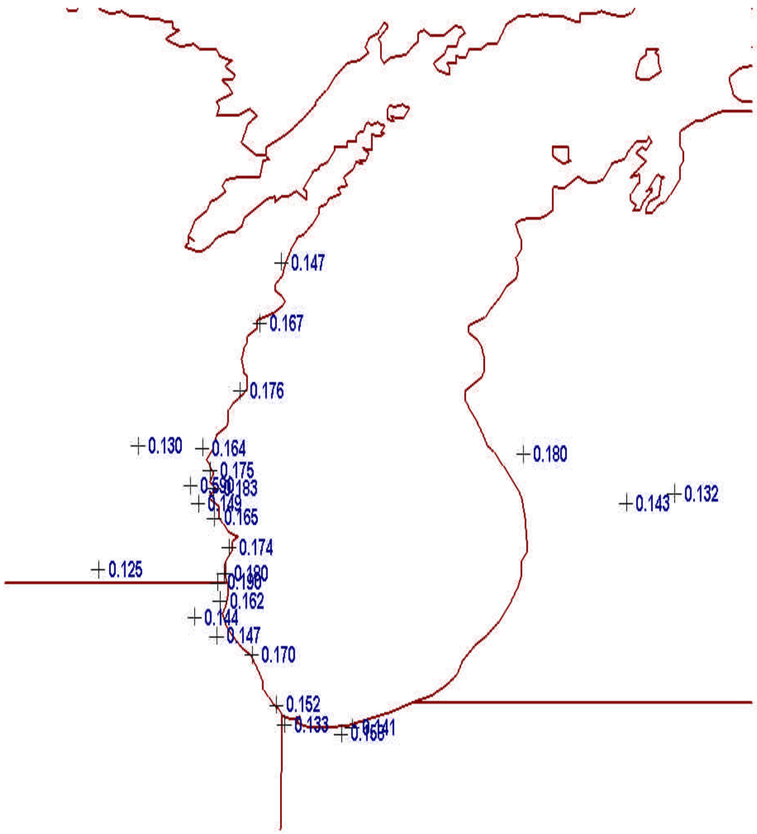
Figure 2 shows the sites in violation (i.e., design values $\geq$ 0.12 ppm) for 1987 – 1989 (i.e., the 3-year period used to establish the original 1-hour nonattainment classifications) and for 1997 – 1999. (Note, there were only two sites in violation for 1998 - 2000 [Pleasant Prairie at 0.126 ppm and Sheboygan at 0.130 ppm] and no sites in violation for 1999 – 2001.) The table above and Figure 2 show:

- The spatial extent of ozone violations has decreased considerably over the past 10 years, from 30 sites in violation in the late 1980's to 6, 2, 0 sites in the past three 3-year periods.

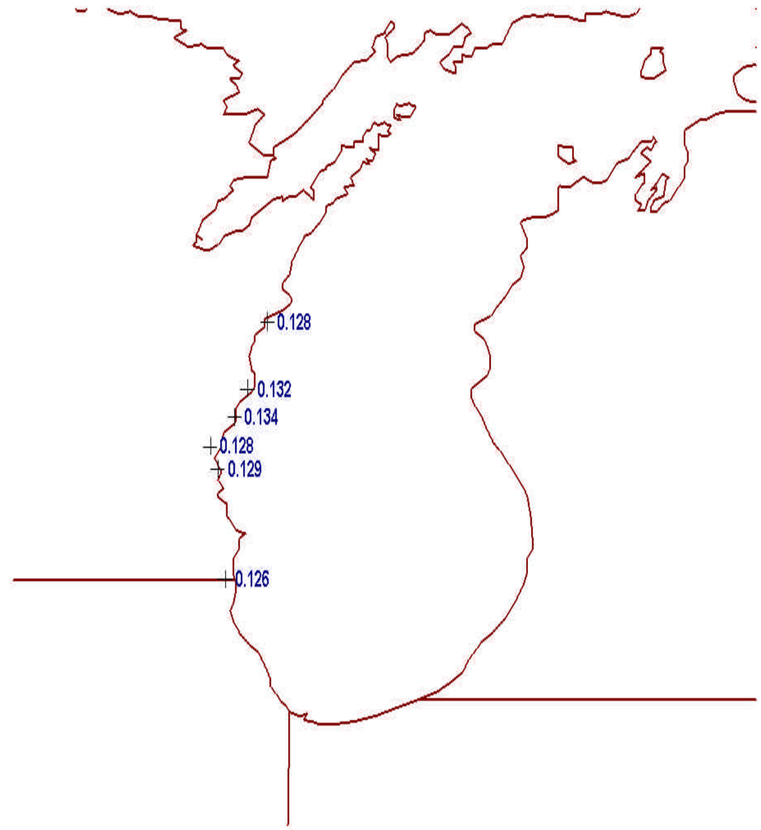
- The magnitude of peak ozone design value has decreased considerably over the past 10 years, from 0.19 ppm in the late 1980's to 0.134, 0.130, 0.124 ppm in the past three 3-year periods.

Figure 2. 1-Hour Ozone Design Values (≥ 0.12 ppm)

1987 – 1989



1997 – 1999



Statistical Analyses
Given the strong effect of meteorology on ambient ozone levels (as noted above), the year-to-year variations in meteorology can make it difficult to assess trends in ozone air quality. Four approaches were considered to adjust ozone trends for meteorological influences:

> Time Series: "Use of Time Series Methods to Detect Ozone Trends", M. Rizzo and P. Scheff, June 2000
>
> Similar Days: "Midwest Ozone Trends on Meteorologically Similar Days", D. Kenski (LADCO), October 2000
>
> Rao-Zurbenko: "Eight-Hour Ozone Trends in the Lake Michigan Ozone Nonattainment Areas", B. Smith and B. Adamski, Journal of Air & Waste Management, 48:1204-1206 (1998) and "Space and Time Scales in Ambient Ozone Data", S. Rao, I. Zurbenko, R. Neagu, P. Porter, J. Ku, and R. Henry, Bulletin of the American Meteorological Society, 78:2153-2166 (1997).
>
> Cox-Chu: "Trends in Daily Maximum 1-Hour Ozone in Selected Urban Areas", 2001.

These analyses are addressed separately below.

Time Series: This approach examined trends based on a time-series regression model of daily peak 1-hour ozone values as a function of temperature, wind speed, wind direction, and time. The analysis considered 10 sites within close proximity of Lake Michigan, as well as three upwind (background) sites with data since about 1980.

The analysis consisted of the following steps:

- Transform the ozone data to the natural log of the daily peak ozone concentration for each site for the months May through September. (Note, 1-hour and 8-hour peaks were treated separately.)

- SAS was used to calculate the cross-correlations between the daily peak ozone concentration and meteorology (temperature, wind speed, and wind direction). The results of the cross-correlation analyses were used to determine which variables and lags of the independent meteorological variables were significant in predicting ozone. For all cases, the current day's daily peak ozone was correlated to the current day's maximum temperature, the previous day's average wind speed, and the current day's wind direction. Additional terms in the equation included one for the interaction between maximum temperature and average wind speed, and one for time in the form of the year and day.

- Calculate regression coefficients for the meteorological variables, time, and the auto-correlation associated with the error term of the ozone time series.

- Calculate the trend in ozone from the regression coefficient for time.

The results of this analysis are presented in Tables 1(a) and 1(b). The major conclusions of this study are as follows:

- Changes in ozone concentration are not consistent from site to site. For the 12 sites with at least 14 years of data, the trends in the maximum 1-hour ozone concentrations ranged from -0.88 (Evanston) to 1.4 (Door County) % per year, and the trends in the maximum 8-hour ozone concentrations ranged from -0.97 (Milwaukee) to 1.6 (Door County) % per year[3].

- The temperature-ozone relationship varies from site to site as well as year to year.

- The largest decreases are seen at sites near Lake Michigan and in the vicinity of the Milwaukee-Chicago source region. Smaller decreases, or even increases are seen at lake-shore monitors located further downwind.

- Regional background and concentrations out of the major source areas have not been decreasing. In fact, over the period 1990 to 1998, concentrations at the downwind Ozaukee and far downwind Door County monitors, and background Effingham and Braidwood monitors have all been increasing.

- While there have been significant decreases in the one-hour peak ozone concentrations, peak concentrations have been shifted further downwind and regional background concentrations are not decreasing.

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[3] Note that a "statistically significant" trend means that it is probably true (not due to chance), but not necessarily important. The trends here were evaluated using a statistical test to judge the probability of obtaining the given results purely by chance. This probability decreases as the relationship among variables becomes stronger and more apparent. A probability of 0.01 means that there is a 1% chance that a given relationship between variables (e.g., the slope of a trend line) is strictly due to chance. Generally, a p-value of 0.05 is used as the threshold for statistical significance; relationships with p-values less than 0.05 are assumed to be real and not due to chance.

Table 1 (a). Summary of 1-Hour Trends Based on Time Series Analysis

	Site	*Years*	*Trend (%/year)*	*95% C.I.*
Wisconsin				
	Chiwaukee	88-98	-1.10	0.65
	Racine	80-98	-0.55	0.43
	Milwaukee-UWM-North	80-98	-1.00	0.55
	Waukesha	85-98	-1.10	0.53
	Grafton	80-98	-0.42	0.55*
	Newport	90-98	+1.40	0.99
Michigan				
	Muskegon	80-98	-0.50	0.71*
Indiana				
	Hammond	80-98	+0.22	0.47*
Illinois				
	Evanston	80-98	-0.88	0.41
	Waukegan	80-98	-0.40	0.44*
	Braidwood	92-98	+3.40	1.50
	Springfield	85-98	-0.49	0.41
	Effingham	83-98	-0.75	0.34

** = not statistically significant*

Table 1 (b). Summary of 8-Hour Trends based on Time Series Analysis

	Site	*Years*	*Trend (%/year)*	*95% C.I.*
Wisconsin				
	Chiwaukee	88-98	-0.82	0.69
	Racine	80-98	-0.54	0.41
	Milwaukee-UWM-North	80-98	-0.97	0.67
	Waukesha	85-98	-0.82	0.49
	Grafton	80-98	-0.40	0.53*
	Newport	90-98	+1.60	1.10
Michigan				
	Muskegon	80-99	-0.15	0.80*
Indiana				
	Hammond	80-98	+0.05	0.48*
Illinois				
	Evanston	80-98	-0.80	0.46
	Waukegan	80-98	-0.26	0.47*
	Braidwood	92-98	+4.20	1.80
	Springfield	85-98	-0.32	0.49*
	Effingham	83-98	-0.81	0.41

Similar Days: This approach examined trends on days with similar (ozone conducive) meteorology by regression. The analysis considered 15 sites with ozone data since about 1980.

The analysis consisted of the following steps:

- Classify days by meteorological conditions (e.g., temperature, wind speed, and wind direction).
- Select those days with ozone conducive conditions (i.e., low wind speeds [< 5 mph], southerly-westerly wind directions, and warm temperatures [> 85^{o}F]).
- Identify the daily peak 1-hour ozone values for single day episodes and the first day of multi-day episodes. Selecting only one day from each episode assures the independence of each observation (i.e., it minimizes the possibility that correlated observations will bias the results of the analysis).
- Log-transform these data to make the data more normally distributed.
- Plot these data for each year and calculate the regression line through the data points.
- Identify the % change per year by the slope of the regression line.

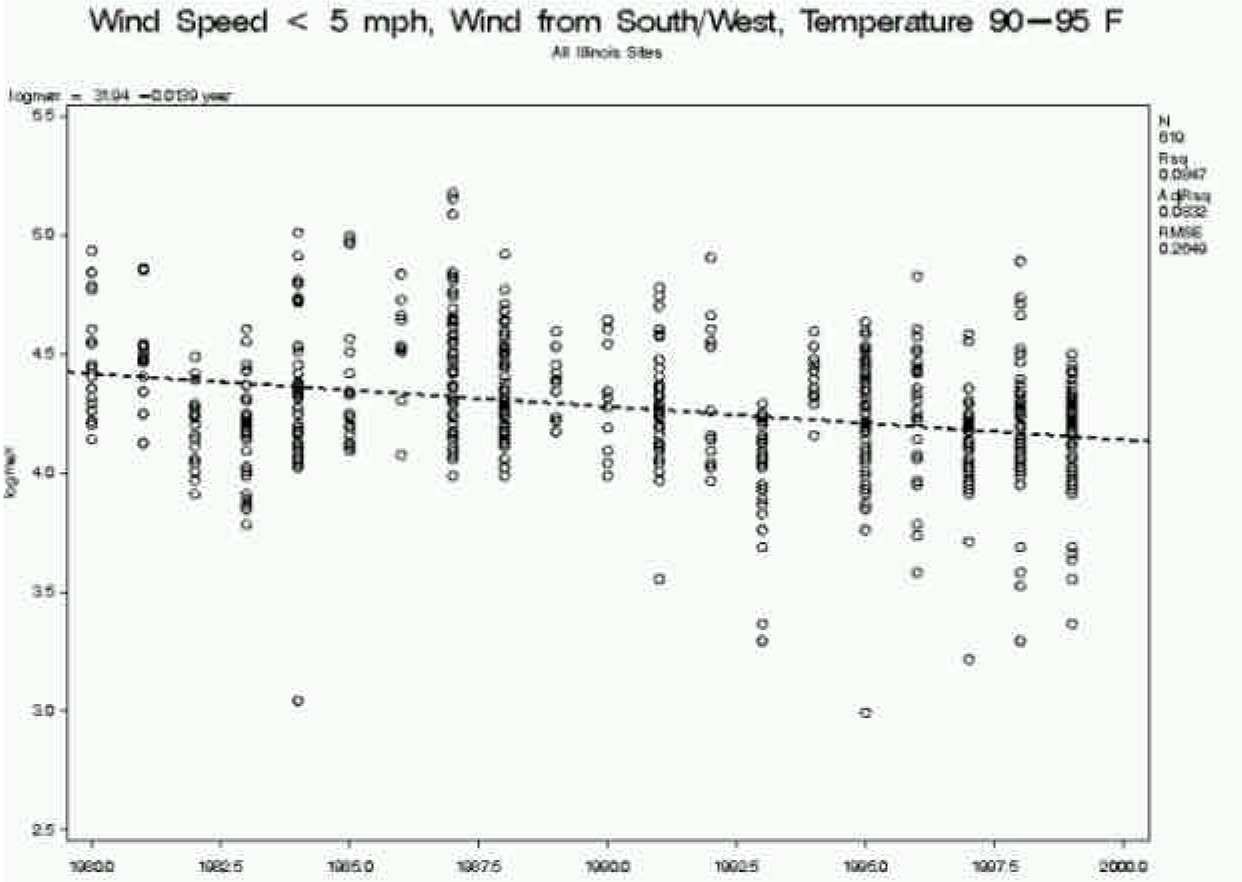
The results of this analysis are presented in Table 2 and Figure 3. The major conclusions of this analysis are:

- The urban sites in northeast Illinois and southeast Wisconsin show a 1 – 2% per year decline in 1-hour peak ozone levels on the days that are most conducive to ozone formation. Changes in these extreme values should be more obvious than changes in values averaged over all conditions.
- The sites farther downwind (e.g., Muskegon, MI) show smaller or no decreases in 1-hour peak ozone levels.

Table 2. Summary of 1-Hour Trends Based on Similar Days Approach

	Site	*Years*	*Trend (%/year)*	*p*
Wisconsin				
	Kenosha	80-99	-1.48	0.01
	Racine	80-99	-2.19	< 0.01
	Milwaukee-Blakewood	84-99	-1.68	0.05
	Milwaukee-Appleton Ave	80-99	-1.03	0.08
	Milwaukee-Alverno	84-99	-1.68	0.05
	Milwaukee-UWM-North	80-99	-2.25	< 0.01
	Milwaukee-Bayside	85-99	-1.37	0.10
	All WI Sites	80-99		
Michigan				
	Muskegon	80-99	0.18	0.61*
Illinois				
	Chicago-SE Police	81-99	-0.25	0.70*
	Chicago-Taft	80-99	-2.03	< 0.01
	Cicero	82-99	-1.61	< 0.01
	Evanston	80-99	-1.14	0.02
	Deerfield	80-99	-1.03	0.06
	Libertyville	80-99	-0.87	0.08
	Waukegan	80-99	-0.75	0.21*
	All IL Sites	80-99	-1.38	< 0.01

* = *not statistically significant*



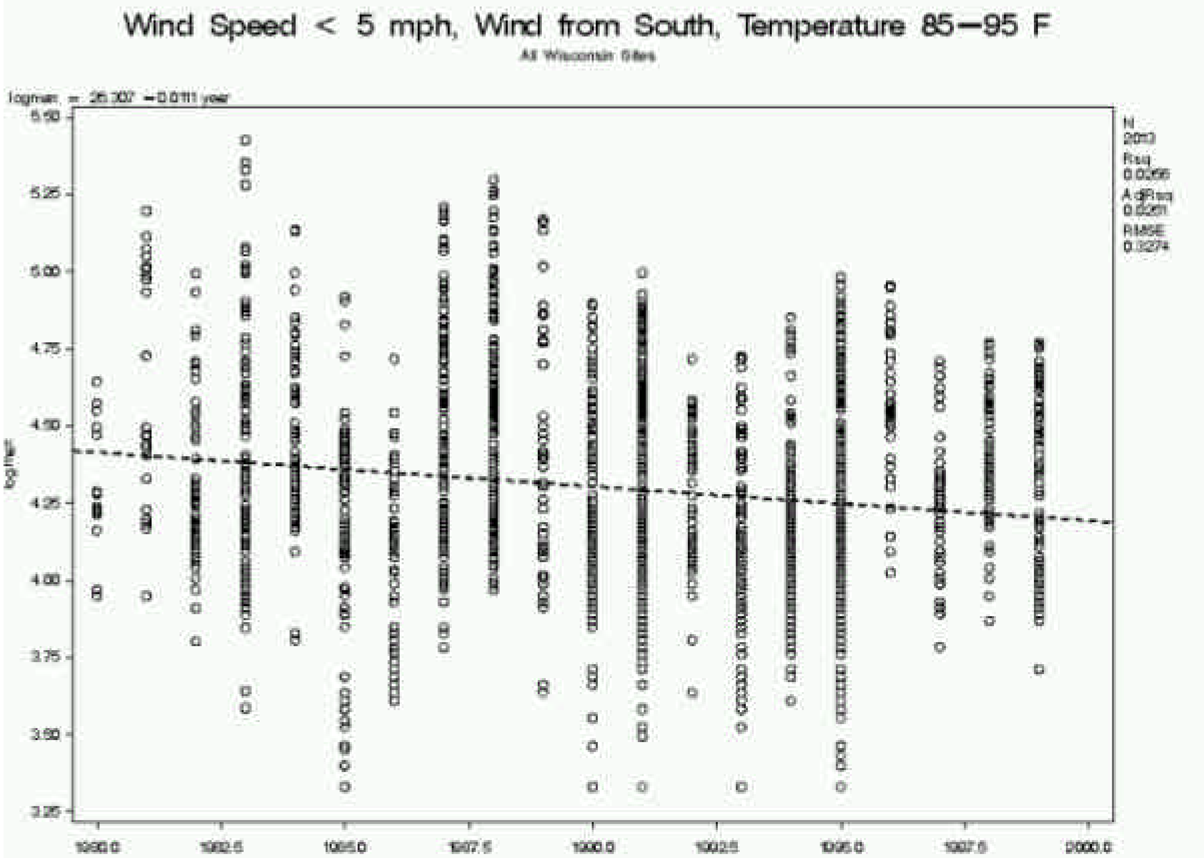


Figure 3. 1-Hour Trends Based on Similar Days Approach

Rao-Zurbenko: This method, which was developed by Professors S.T. Rao and I. Zurbenko at the State University of New York at Albany, attempts to filter-out or moderate the influence of meteorology on ambient ozone levels, using surface temperature as a surrogate for all meteorological variables that affect ozone. By filtering-out most of the influence due to the synoptic (several days, "short-term") and seasonal (annual) weather fluctuations that yield varying ozone levels, the remaining portion of the ozone spectra can hypothetically be called the "baseline" or "long-term" component of the ozone time series. This long-term ozone is assumed to be attributed mostly to local anthropogenic influences. Linear regression techniques and moving average filters can help identify quasi-linear trends and rates of change in the long-term baseline ozone time series.

The RZ method was applied to peak daily 1-hour and 8-hour ozone concentrations from 10 sites located near Lake Michigan. The analysis consisted of the following steps:

- Calculate the log of the peak daily 1-hr and running 8-hr average ozone annually during 15 April – 15 Oct during 1980 – 1999 (20 years) at each of these sites.

- Calculate peak daily 1-hour and running 8-hour average temperature from the nearest National Weather Service (NWS) site to each ozone site. (Temperature is the single biggest weather variable that influences fluctuations in ozone.)

- Select filter parameters in order to decompose the short-term and seasonal components from the original ozone series:
  - "k" number of iterations: 5 (typical of RZ runs)
  - "m" points (calendar days) across which the time-moving filter is applied for each occurrence: 15 (typical value for RZ runs)

- Run linear regression against the time-shifted peak-daily temperature to identify and remove (mostly) fluctuations in peak daily ozone due to changes in the peak daily temperatures. (Note, the analysis was also done for several "two meteorological parameter" sets (i.e., temperature and either solar radiation or relative humidity). Employing the second parameter yielded only a marginal change in the results from using temperature only. In the Lake Michigan air shed, peak daily temperature is the dominant meteorological variable in influencing peak daily ozone. Nevertheless, for those sites near the Lake Michigan shoreline, it would be interesting if the daytime spectra of wind speed and direction could be parameterized into a scalar quantity for input to RZ. This weather feature might have a sizable impact on RZ-normalized ozone time series because most sites near Lake Michigan often experience their highest ozone on summer days that have a onshore air flow - i.e., the lake breeze.)

- Select parameters for a 2^{nd} application of the filter to identify the long-term component of the temperature-ozone spectra:
  - "k" number of iterations: 3, "m" calendar days: 365 (annual)

- RZ output products include estimates of site-specific annual percent change in temperature-ozone and a time series graph of the variation of the ozone from the temperature-adjusted mean ozone value.

The results of this analysis are presented in Tables 3(a) and 3(b) and Figures 4 (a) and 4(b). The thick line in each panel represents the RZ calculations of the long-term trend in peak daily ozone.

The major conclusions of this study are as follows:

- There are negligible differences between the 1-hour and 8-hour trend rates and curves.

- Early in the study period, the curves exhibit a mostly downward trend on the order of –0.2 to –0.4% per year.

- 1988 was one of the hottest summers and highest ozone seasons on record in the Lake Michigan area. Given the "bump-up" in the thick curve for this year, it is apparent that the filter and RZ's linear regression do not remove all of variations in peak daily ozone due to changes in the peak daily temperature, especially during such extremely hot summers.

- Between 1989 and 1992, most sites had a relatively sizeable decrease in the long-term trend on the order of –1.0% per year. This is likely due to a combination of factors (e.g., trend curve follows an abnormally high year [1988], these years were cooler than normal, and the implementation of several ozone control programs).

- After 1994, most sites had an increase due to another very hot summer in 1995 and, possibly, increases in ozone precursor emissions (i.e., NOx). This increase is reflected by lower trend rates for the 1980-1999 period compared to the 1980-1995 period.

- Geographically, different ozone trend patterns were calculated. On the western side of the Lake (eastern WI and northeastern IL), ozone trends were generally downward. On the southern and eastern sides of the Lake (northwestern IN and western MI), however, ozone trends were weak or nonexistent.

Table 3 (a). Summary of 1-Hour Trends Based on Rao-Zurbenko Approach

	Site	*Years*	*Trend (%/year)*	*95% C.I.*
Wisconsin				
	Kenosha	80-95	-0.77	0.43
		80-99	+0.06	0.27*
	Racine	80-95	-0.89	0.45
		80-99	-0.13	0.28*
	Milwaukee-UWM-North	80-95	-0.77	0.42
		80-99	-0.66	0.26
	Waukesha	80-95	-1.16	0.38
		80-99	-0.49	0.25
	Slinger	80-95	-0.52	0.35
		80-99	-0.27	0.22
	Madison	80-95	-1.00	0.35
Michigan				
	Muskegon	80-95	+0.32	0.46*
		80-99	+0.28	0.29*
	Grand Rapids	80-95	-0.60	0.45
		80-99	-0.33	0.30
Indiana				
	Hammond	80-95	-0.51	0.42
		80-99	+0.16	0.26*
Illinois				
	Evanston	80-95	-1.29	0.39
		80-99	-0.35	0.25

** = not statistically significant*

Table 3 (b). Summary of 8-Hour Trends Based on Rao-Zurbenko Approach

Site	*Years*	*Trend (%/year)*	*95% C.I.*
Wisconsin			
Kenosha	80-95	-0.57	0.44
	80-99	-0.06	0.28*
Racine	80-95	-0.88	0.44
	80-99	-0.07	0.28*
Milwaukee-UWM-North	80-95	-0.82	0.40
	80-99	-0.88	0.26
Waukesha	80-95	-1.22	0.39
	80-99	-0.58	0.27
Slinger	80-95	-0.60	0.36
	80-99	-0.48	0.24
Madison	80-95	-0.40	0.36
Michigan			
Muskegon	80-95	+0.29	0.44*
	80-99	+0.08	0.30*
Grand Rapids	80-95	-0.38	0.48*
	80-99	-0.31	0.32*
Indiana			
Hammond	80-95	-0.41	0.43*
	80-99	-0.35	0.31
Illinois			
Evanston	80-95	-1.32	0.39
	80-99	-0.67	0.26

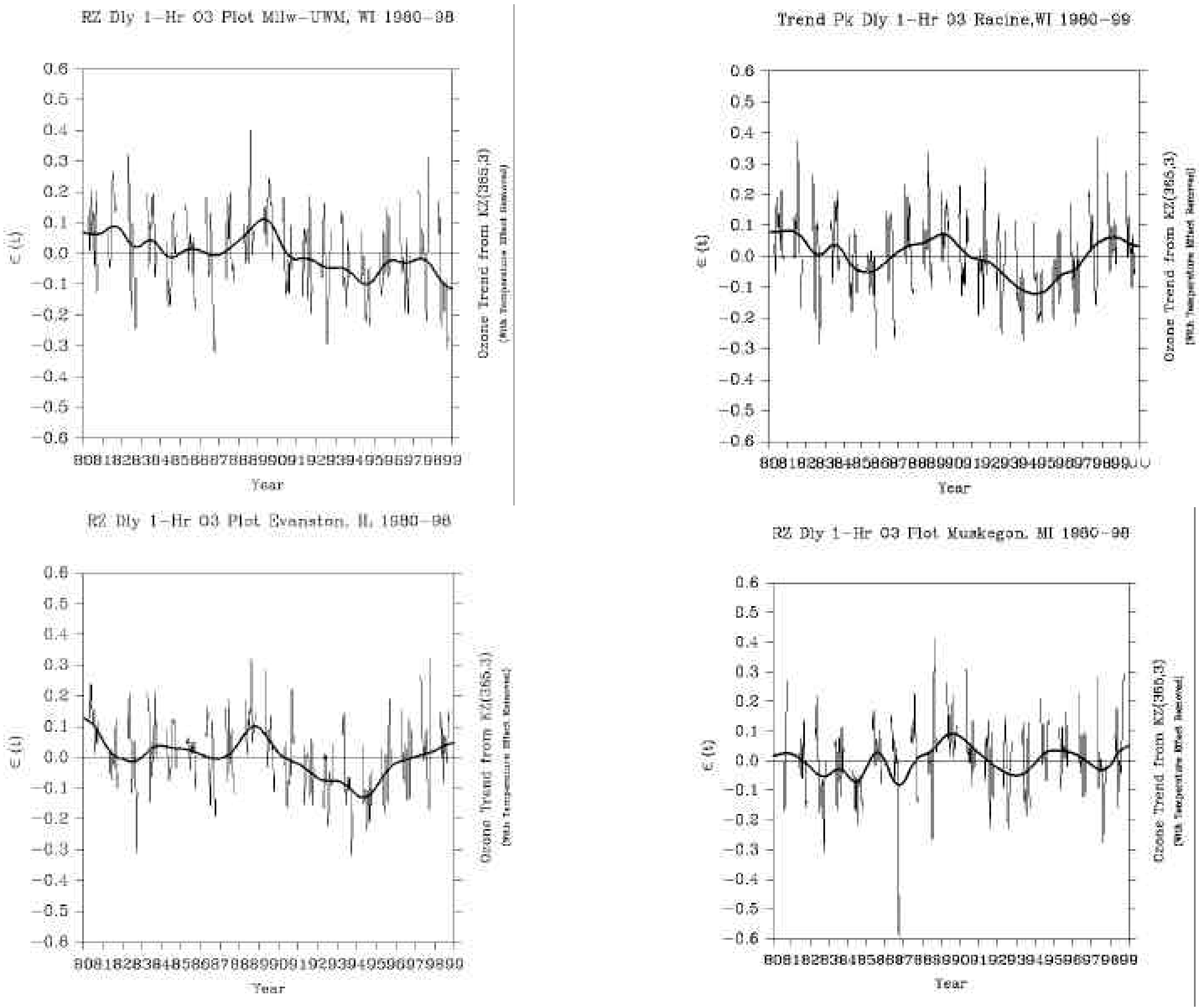


Figure 4 (a). 1-Hour Trends Based on Rao-Zurbenko Approach

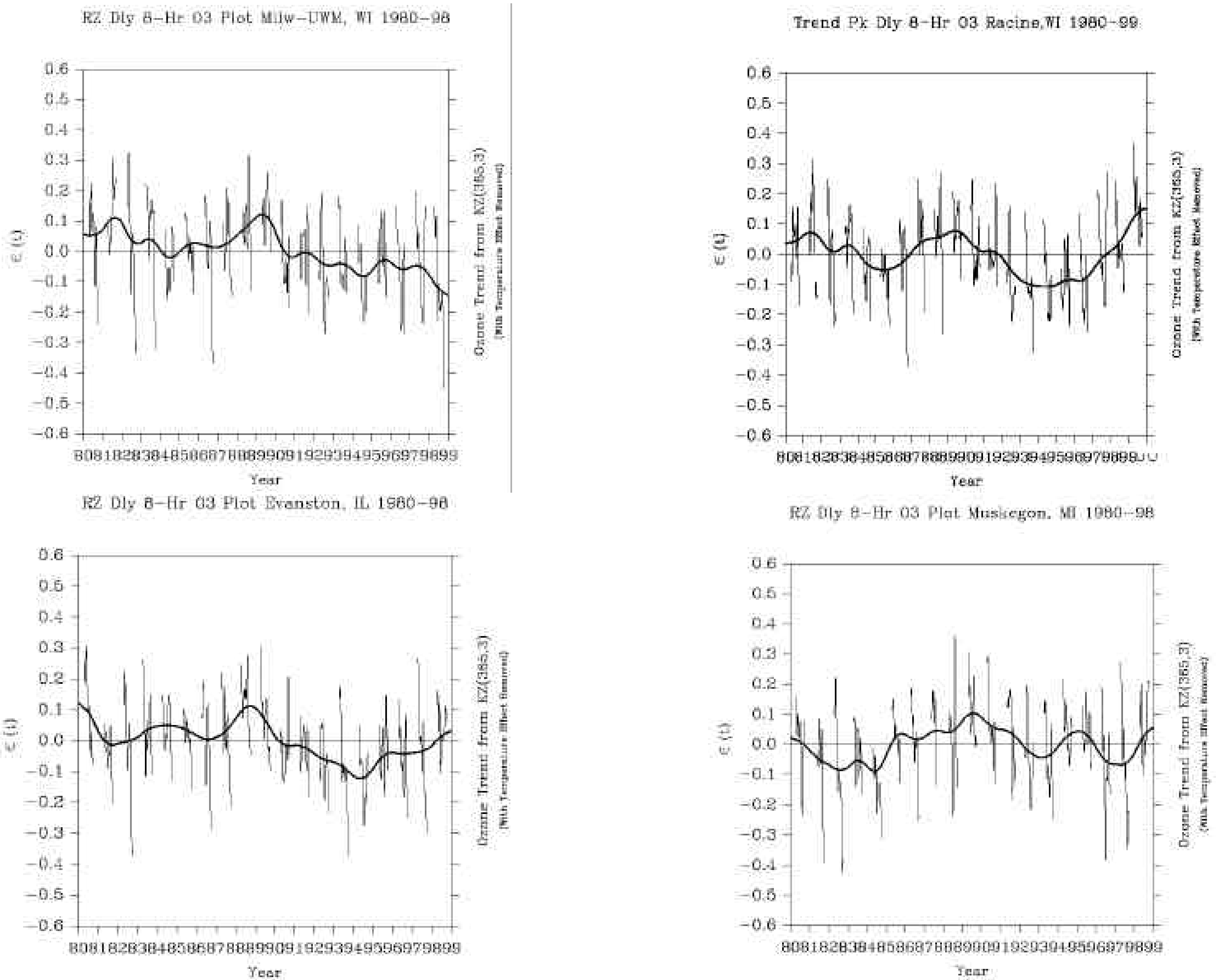


Figure 4 (b). 8-Hour Trends Based on Rao-Zurbenko Approach

Cox-Chu: This method uses a statistical model to "remove" the annual effect of meteorology on ozone and allows for a non-linear trend over a multi-year period.

This approach consisted of the following steps:

- Identify the daily peak 1-hour (and 8-hour) ozone concentration in a given urban area. (Note, the ozone data used in the trends analysis are not taken from a single monitoring site, but rather the daily maximum 1-hour ozone from among all available monitoring sites within the CMSA. This means that the monitor producing the highest value can vary from day to day.)

- Apply a generalized linear model to relate daily peak ozone levels to four meteorological variables (i.e., daily peak 1-hour temperature, midday average relative humidity, morning and afternoon wind speed and wind direction, and morning mixing heights). Exploratory analyses show that daily peak 1-hour ozone is a non-linear function of Julian day, relative humidity, and the long-term trend.

The results of this analysis for Chicago, Milwaukee, and Muskegon are presented in Figures 5 (a), 5 (b), and 5 (c). The top two panels of each figure show the results with and without meteorological co-variates. The bottom two panels show the same comparison except that the trend component has been smoothed using a natural cubic spline. Data values represented on the y-axis are logarithmic (-0.2 to +0.2) and centered on 0. Changes across years can be interpreted in a fractional or relative sense. For example, a change on the y-axis from 0.2 to 0.1 represents approximately a 10 percent improvement in ozone levels between two corresponding years on the x-axis.

Figure 5 (a)

Chicago 1-Hour Ozone Trends

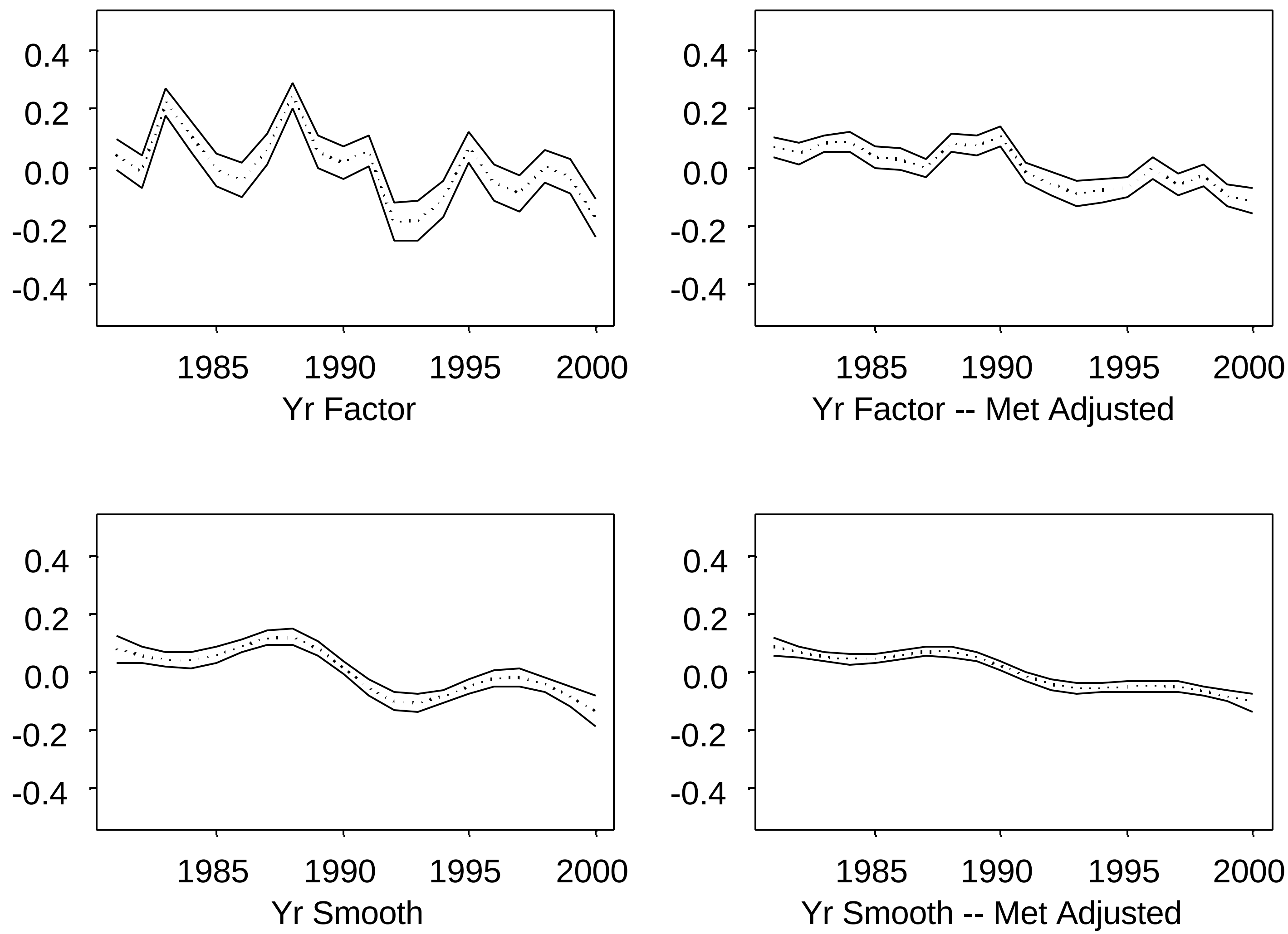


Figure 5 (b)

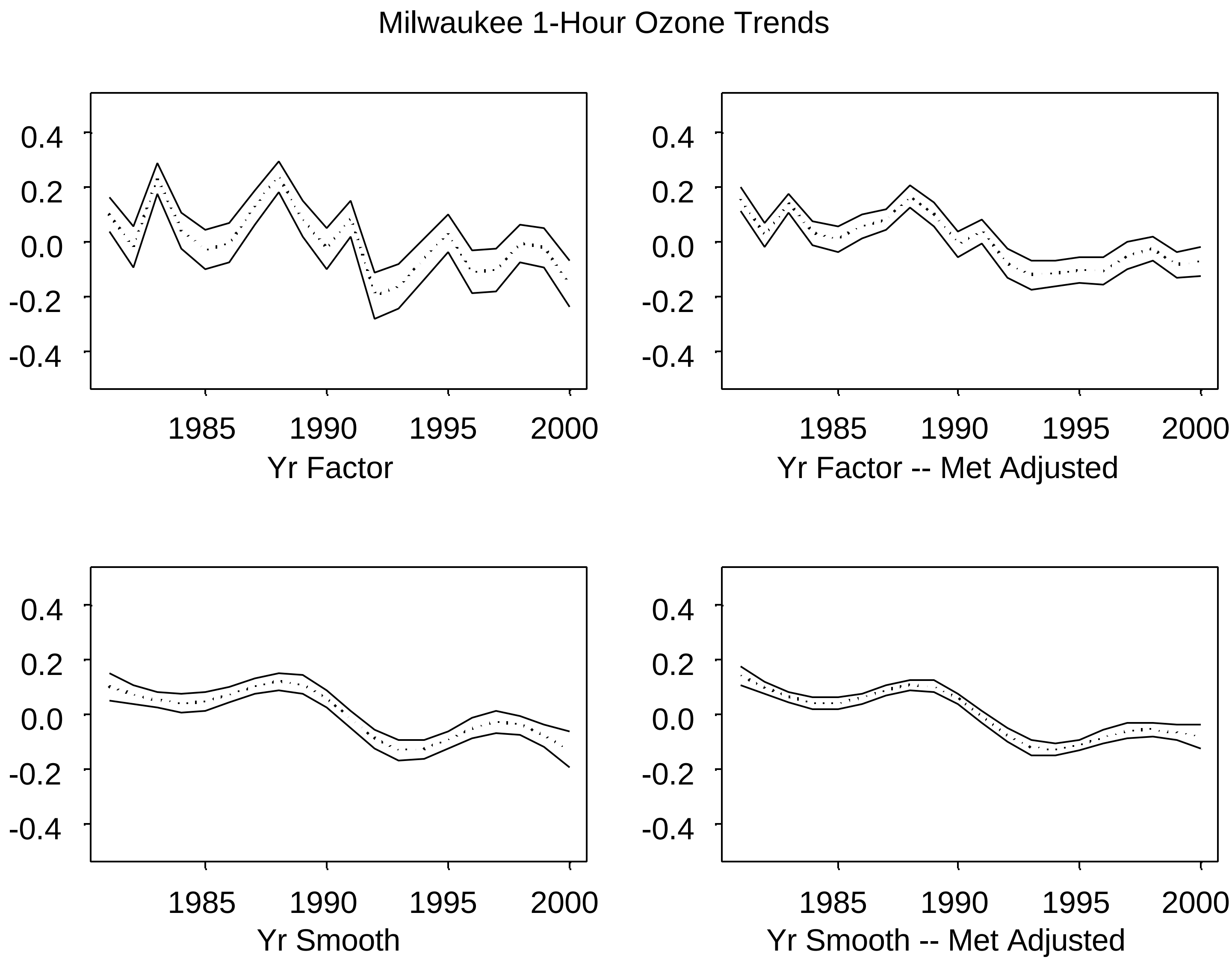
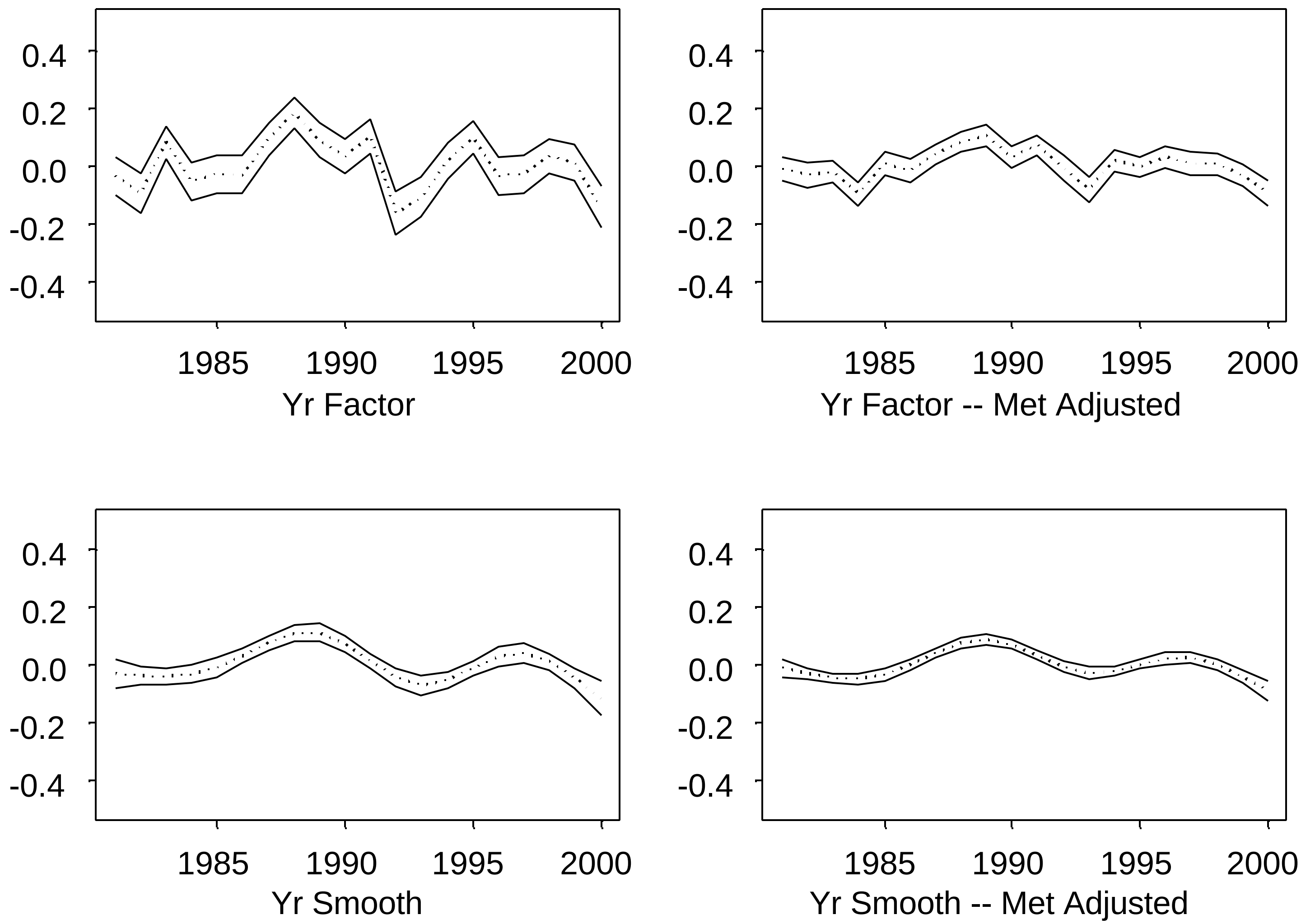

Milwaukee 1-Hour Ozone Trends
0.4
0.2
0.0
-0.2
-0.4
1985
1990
1995
2000
Yr Factor
Yr Factor -- Met Adjusted
Yr Smooth
Yr Smooth -- Met Adjusted

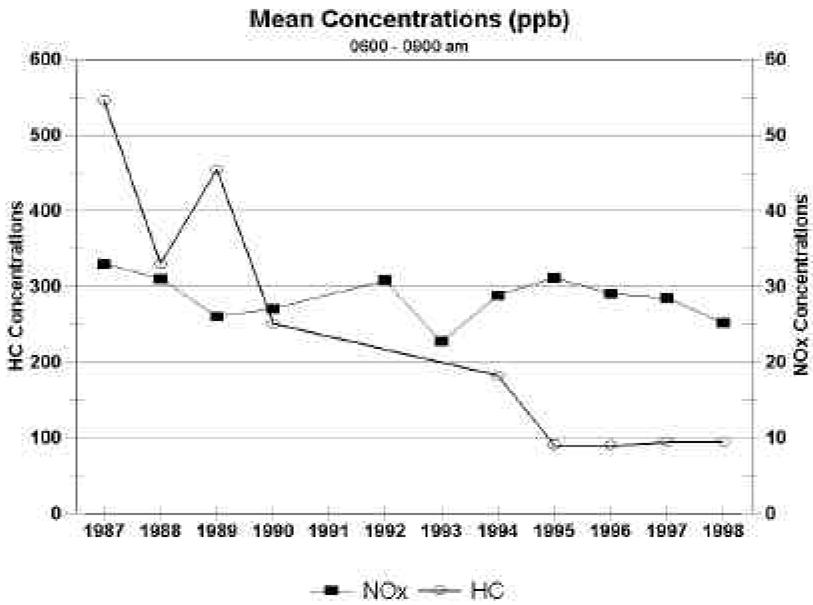
Figure 5 (c)

Muskegon 1-Hour Ozone Trends



Ozone Precursor Trends

Local surface ozone precursor data are very limited. There is only one site (UWM-North in Milwaukee) with as much as 10 years of both VOC and NOx data. These data indicate that VOC (represented here as non-methane hydrocarbon concentrations or NMHC) and, to a much lesser degree, NOx concentrations have declined since the mid-1980's (see Figure 6 below). The decrease in VOC concentrations is associated with (and perhaps explains) the decrease in local ozone concentrations



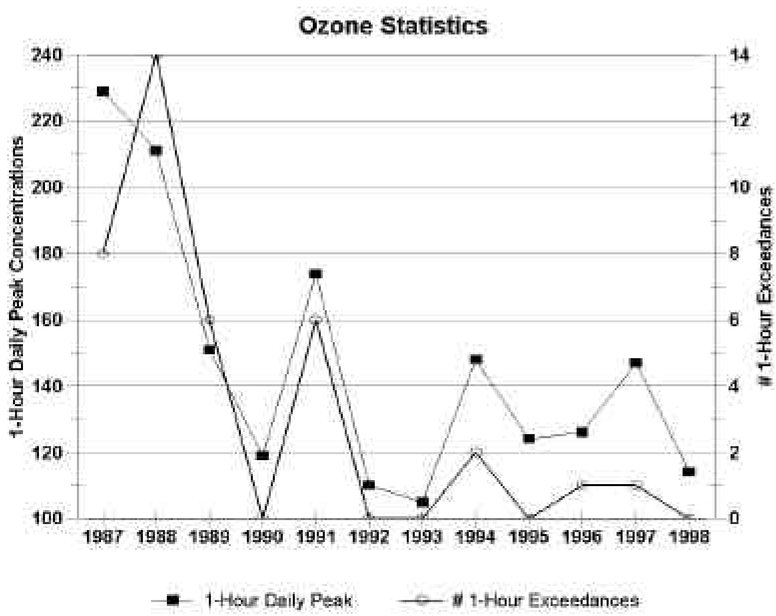


Figure 6. Trends in Ozone Precursor and Ozone Concentrations – Milwaukee, WI

Ozone precursor data are also available from the Lake Michigan regional Photochemical Assessment Monitoring Stations (PAMS), but only since the mid-1990's (see Figure 7 below). There is an insufficient record of data from these stations to perform any long-term trends analysis at this time. Given the importance of this analysis (both for 1-hour maintenance purposes and 8-hour attainment planning), it is critical that these stations be continued.

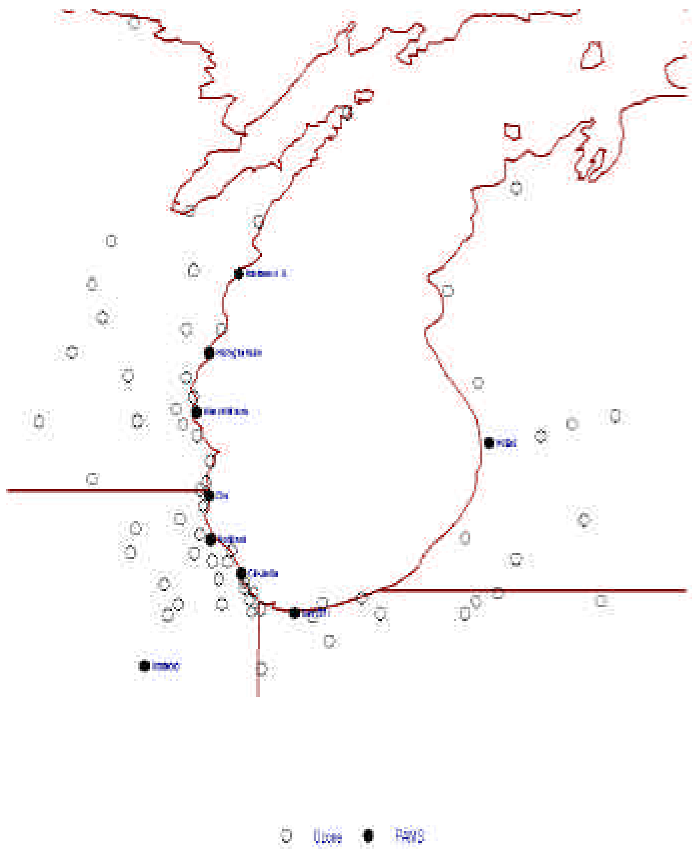


Figure 7. PAMS Monitoring Stations in the Lake Michigan Area

Background Trends

Upwind air quality data are also very limited. The mean incoming (regional) ozone levels since 1980 were estimated based on surface measurements collected at several sites in an area approximately 50 miles southwest of Chicago (i.e., near Braidwood, IL). A plot of the mean midday upwind surface ozone concentration for the high ozone (1-hour exceedance) days, the aircraft sampling days, and all days (June – August) from 1981 to 1999 is provided below.

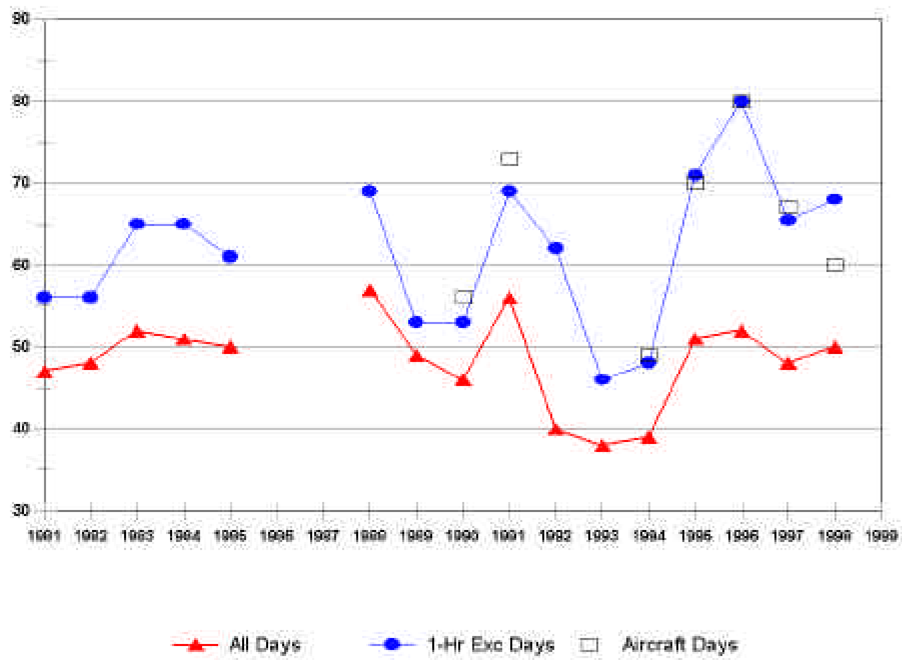


Figure 8. Upwind Ozone Concentrations

This figure shows:

- Mean midday upwind surface ozone levels have remained fairly steady over the past 20 years, except for the period 1992 – 1994. (Note, the data from 1992 – 1994 were taken from a different site in the area, which may explain the differences between this period and the rest of the 20-year period.)

- Mean midday upwind surface concentrations over the past 20 years are about 45 - 55 ppb for all summer days, and about 55 – 75 ppb for the high ozone days. Assuming an average surface : aloft difference of about 10 ppb (see STI, 1994), this suggests that the incoming (aloft) ozone concentrations are on the order of 60 ppb during the summer and 65 – 85 ppb on high ozone days.

Results from Other Studies
Additional information on trends in the Lake Michigan area is available from other studies. A summary of the findings from these studies is provided below:

(1) "Data Analysis for a Better Understanding of the Weekday/Weekend Ozone and PM Differences", prepared for the Coordinating Research Council by Atmospheric and Environmental Research, Inc., June 2001.

This analysis was performed to examine the weekly cycle of ozone and particulate matter concentrations in three areas: Atlanta, Chicago, and Philadelphia. The results of this analysis are summarized in Tables 4(a) and 4(b), and Figure 9. The major conclusions of this study are as follows:

- Mean daily peak ozone values were greater on Saturday and Sunday compared to weekdays for both 5-year periods. Note, the mean daily peak values for 1995 –1999 are less than those for 1986-1990.
- The difference between weekend and weekday mean ozone concentrations ranged from 4 – 10 ppb in 1986 –1990 and 5 – 11 ppb in 1995 – 1999.
- Diurnal profiles indicate that: (a) the average weekend ozone levels were higher than weekday levels for virtually every hour, (b) ozone levels on weekend morning were higher than those for weekday mornings, indicating less titration by NO on weekend mornings, and (c) the time of NO-ozone cross-over was 1 – 3 hours earlier on weekends.

(2) Fiore, A.M., Jacob, D.J., Logan, J.A., Yin, J. H., 1998, "Long-term trends in ground level ozone over the contiguous United States, 1980 – 1995", Journal of Geophysical Research, 103 (D1), 1471 – 1480.

Based on an examination of nationwide trends in median and 90th percentile ozone concentrations for the period 1980 – 1995, this study found that trends were insignificant over most of the continental U.S.; and decreasing trends were clustered in a few metropolitan areas, including Chicago.

(3) Lin, C. C.Y., Jacob, D.J. and Fiore, A.M., 2001, "Trends in exceedances of the ozone air quality standard in the continental United States, 1980 – 1998", Atmospheric Environment, 35 (2001), 3217 – 3228.

Based on an examination of nationwide trends in the number of exceedance days of the 1-hour and 8-hour ozone NAAQS for the period 1980 – 1998, this study found that

- downward trends occurred in several areas, including "the western back of Lake Michigan";

- o binning the data by temperature to remove the effect of interannual variability in weather revealed stronger and more significant trends;
- o downward trends for the 1-hour NAAQS are greater and more significant than those for the 8-hour NAAQS, but there is a close correspondence between both standards in regions where significant downward trends were found (which suggests that controls enacted to improve 1-hour ozone levels were also effective in improving 8-hour ozone levels); and
- o except for the southwest, quadrants of the U.S. experienced significant downward trends in ozone exceedances over the 19-year period, although mostly over the 1980s (i.e., there was little change during the 1990s).

(4) USEPA, 2001, "National Air Quality and Emissions Trends Report, 1999", EPA 454/R-01-004, March 2001.

This document, which is USEPA's 27th annual report documenting air pollution trends in the United States, highlights USEPA's most recent assessment of the nation's air quality. It features information for the criteria pollutants and hazardous air pollutants, as well as relevant ambient air quality information for visibility impairment and acid rain. Findings of relevance for the Lake Michigan ozone situation include:

- o there was no significant change in the 2^nd daily maximum 1-hour (and 4^th maximum 8-hour) ozone levels over the period 1990 - 1999 in the metropolitan statistical areas in the Lake Michigan area (i.e., Chicago, Gary, Racine, Kenosha, and Milwaukee); and
- o trends in CO concentrations, which may be indicative of trends in VOC concentrations in urban areas where motor vehicle emissions are dominant (because of the relationship between motor vehicle Co and VOC [exhaust] emissions), are downward in Chicago and Milwaukee over the period 1990 – 1999.

Table 4(a). Statistics of mean daily maximum one-hour average ozone concentrations (ppm) by day of the week in Chicago, IL.

Site ID	Maximum (ppm)	Day of maximum	Minimum (ppm)	Day of minimum	Max minus min (ppm)	Statistical significance of the difference
1703100014	0.0508	Sunday	0.0419	Wednesday	0.0088	5%
1703100324	0.0552	Sunday	0.0483	Wednesday	0.0069	5%
1703100504	0.0499	Sunday	0.0424	Tuesday	0.0075	5%
1703100634	0.0432	Sunday	0.0326	Tuesday	0.0106	5%
1703100644	0.0502	Sunday	0.0423	Wednesday	0.0079	5%
1703100724	0.0553	Sunday	0.0499	Wednesday	0.0054	5%
1703110034	0.0487	Sunday	0.0396	Wednesday	0.0090	5%
1703116014	0.0491	Sunday	0.0437	Tuesday	0.0053	5%
1703140024	0.0482	Sunday	0.0391	Tuesday	0.0091	5%
1703140064	0.0517	Sunday	0.0434	Tuesday	0.0083	5%
1703170024	0.0559	Sunday	0.0496	Tuesday	0.0063	5%
1703180034	0.0464	Sunday	0.0390	Wednesday	0.0074	5%
1704360014	0.0504	Sunday	0.0424	Wednesday	0.0080	5%
1709700014	0.0500	Sunday	0.0437	Wednesday	0.0063	5%
1709710024	0.0530	Sunday	0.0471	Tuesday	0.0059	5%
1709710074	0.0549	Sunday	0.0500	Tuesday	0.0049	5%
1709730014	0.0495	Sunday	0.0433	Tuesday	0.0062	5%
1719710114	0.0547	Sunday	0.0509	Tuesday	0.0038	5%

Table 4(b). Statistics of mean daily maximum one-hour average ozone concentrations (ppm) by day of the week in Chicago, IL, 1986 – 1990.

Site ID	Maximum (ppm)	Day of maximum	Minimum (ppm)	Day of minimum	Max minus min (ppm)	Statistical significance of the difference
1703100014	0.0606	Sunday	0.0508	Friday	0.0097	5%
1703100324	0.0564	Sunday	0.0499	Friday	0.0065	5%
1703100374	0.0507	Saturday	0.0444	Tuesday	0.0063	5%
1703100504	0.0487	Sunday	0.0408	Tuesday	0.0079	5%
1703100644	0.0591	Sunday	0.0491	Tuesday	0.0099	10%
1703110024	0.0514	Sunday	0.0458	Thursday	0.0056	insignificant
1703110034	0.0548	Saturday	0.0464	Friday	0.0084	5%
1703116014	0.0557	Saturday	0.0484	Friday	0.0074	5%
1703140024	0.0529	Sunday	0.0457	Tuesday	0.0072	5%
1703140034	0.0547	Saturday	0.0471	Friday	0.0076	5%
1703170024	0.0592	Saturday	0.0545	Tuesday	0.0047	10%
1704360014	0.0520	Saturday	0.0443	Friday	0.0077	5%
1709700014	0.0544	Saturday	0.0478	Friday	0.0066	5%
1709710024	0.0567	Saturday	0.0504	Friday	0.0063	5%
1709730014	0.0540	Saturday	0.0480	Friday	0.0060	5%
1808910164	0.0485	Sunday	0.0434	Wednesday	0.0050	5%
1808920084	0.0585	Thursday	0.0550	Tuesday	0.0035	insignificant
1812700244	0.0638	Thursday	0.0595	Friday	0.0043	insignificant

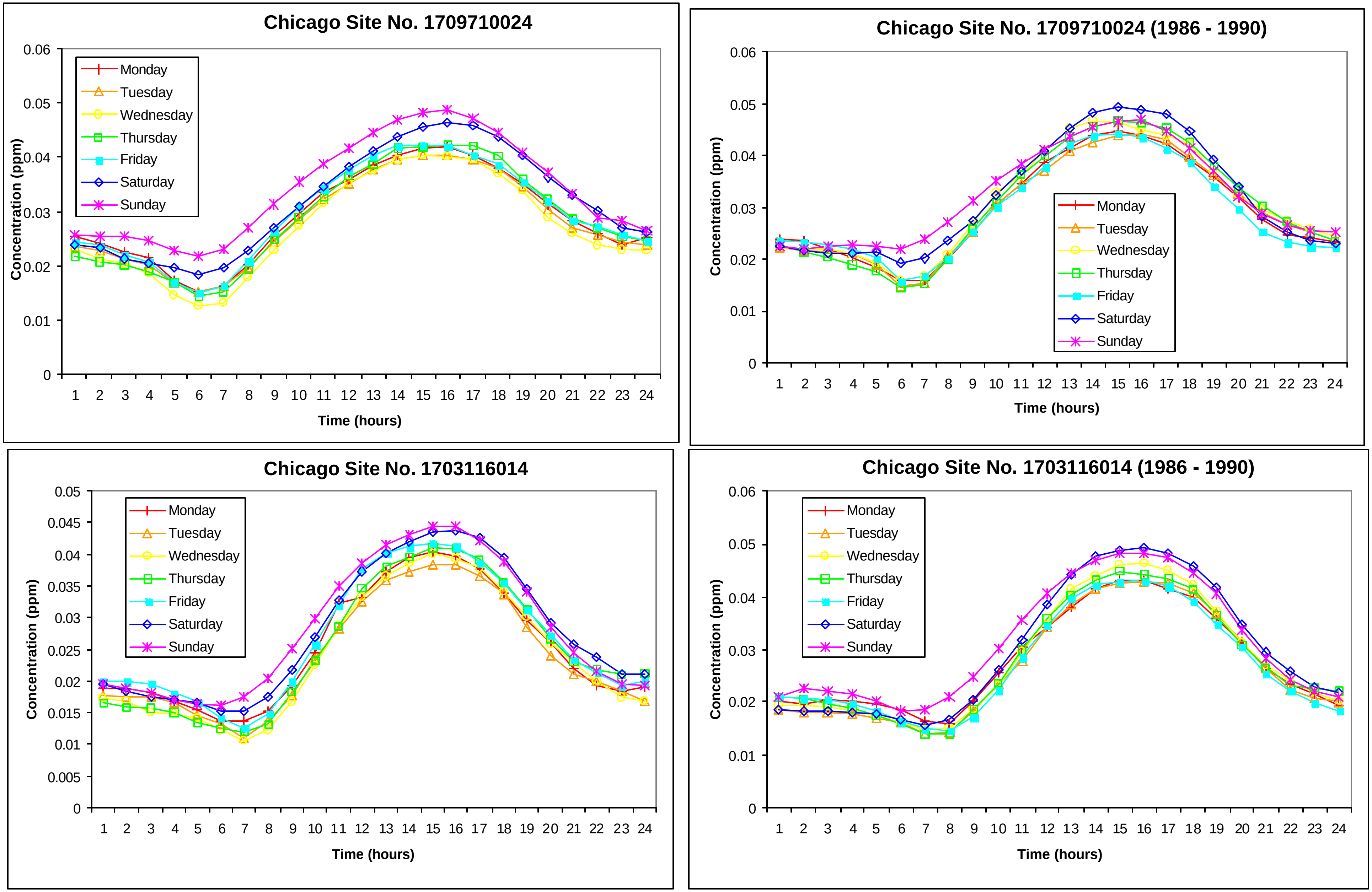


Figure 9. Average Hourly Ozone Concentrations for Downwind (Top) and Upwnwind (Bottom) Monitoring Sites in the Chicago Area for the Periods 1995 – 1999 (Left) and 1986 – 1990 (Right)

Summary

The change in ozone air quality over time provides information on progress toward attainment and the relative effectiveness of control programs. The trends in local ozone concentrations (including basic ozone metrics, such as the number of exceedance days and the design values, and statistical analyses which account for the year-to-year variation in meteorology), local ozone precursor concentrations, and incoming (background) ozone concentrations were considered here.

The key findings from this study are as follows:

- Since 1981, trends in 1-hour peaks are generally downward. In recent years, however, these trends are flatter.

- Most improvement in 1-hour levels is seen at sites near Lake Michigan in the vicinity of the Chicago-Milwaukee area. Less improvement is seen at sites farther downwind.

- Trends at regional (background) sites are generally flat and, possibly, increasing in recent years.

- Trends in 8-hour peaks are similar to those for 1-hour peaks, with some indication of increasing trends in recent years.

Trends analyses should be performed in future years to assess continued attainment of the 1-hour ozone NAAQS and progress toward attainment of the 8-hour ozone NAAQS. To this end, important data needs include ozone data from many of the existing regional ozone monitors and ozone precursor data from the regional PAMS monitoring network.